THE APPLICABILITY OF MPD THRUSTERS TO SATELLITE POWER SYSTEMS*

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The magnetoplasmadynamic (MPD) thruster is currently under development at JPL for a range of applications including deep space propulsion, near Earth payload transportation, and stationkeeping and attitude control of large space structures. Recent experiments tend to confirm past projections that specific impulses from 1000 to 5000 seconds at efficiencies exceeding 50% can be obtained with argon propellant. The high power self-field MPD thruster is fundamentally different than an ion thruster in that it uses electromagnetic forces rather than electrostatic to accelerate a neutral plasma. The MPD thruster has a cylindrically symmetric geometry with an annular anode ring placed at the downstream end of a discharge chamber. The discharge current flows from this anode to a centrally located cathode which extends upstream to the discharge chamber backplate. The propellant is injected through the backplate and flows through the discharge current pattern where it is ionized and accelerated by a self-field Lorentz body force ($\underline{j} \times \underline{B}$). The resulting thrust and specific impulse both depend quadratically on the discharge current, while the thrust efficiency increases in a more linear fashion. For reasonable specific impulse and efficiency levels, discharge currents of order tens of kiloamperes are necessary, leading to power levels of order megawatts. At this power, one MPD thruster can develop over 150 N of thrust in a volume similar to that of one 30-cm ion thruster. This high thrust density and the overall simplicity of the MPD thruster system lead to a low system specific mass and high reliability. The projected thruster efficiency for an argon MPD thruster is compared to that of an argon ion thruster in Fig. 1. The attainable MPD thruster specific impulse depends on the inverse square root of the propellant atomic weight; hence much higher specific impulses can be attained by using lighter propellants. Using helium or hydrogen the attainable specific impulse may be well above 10,000 sec. This specific impulse at thrust levels of tens of newtons makes a MPD propulsion system a candidate for stationkeeping and attitude control of large space structures such as a SPS.

The most attractive application of MPD thrusters to satellite power systems is in the area of electric propulsion for a cargo orbit transfer vehicle (COTV). Calculations have been performed in order to compare the performance of a COTV using an ion or MPD propulsion system. It was assumed that the COTV carried an SPS size payload (millions of kilograms) and that a large solar array supplied power (~ hundred megawatts) to the electric propulsion system. The LEO to GEO trip time was estimated by using a closed form analytical approximation which included factors for steering and drag losses and losses due to Earth shadowing and degradation of the solar array. The propellant for both the MPD and Ion thruster propulsion systems was assumed to be argon. The performance of the ion thrusters was that of a projected 120-cm thruster operating at 5000 and

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8000 seconds with input powers of 69 and 150 kW respectively. The MPD thruster performance was taken from the projections of Fig. 1 to be 57% efficient at 5000 sec with an input power of 6 MW. The results of the calculations for a 2×10^6 kg payload and a 150 MW power supply are presented in Fig. 2. The results show that the MPD propulsion system gives a shorter trip time with the same power and payload when compared to the ion thruster propulsion system at either value of specific impulse. More important than even the trip time benefit, may be the advantage a MPD propulsion system provides in system simplicity. Due to the large amount of input power handled per thruster, a MPD propulsion system needs far fewer thrusters than an ion thruster propulsion system. Therefore the propulsion system will be much simpler and less costly.

Another interesting COTV concept using MPD thrusters is the use of a remote power supply located on the Earth, at GEO, or somewhere in between to transmit power to the COTV in a microwave transmission. For an initial evaluation of this concept, (see Fig. 3), three transmitters were assumed to be in orbit at GEO equally spaced around the Earth. The transmitter longitudes correspond approximately to those of southern Japan, West Germany or southern France, and the western U.S. These locations may be quite practical if the SPS program becomes an international venture. The power supply for the transmitters could be a prototype, a partially completed, or a complete SPS. This concept assumes that the MPD-COTV is equipped with a microwave rectenna to convert the power to D.C. and that the vehicle receives power from only one transmitter at a time. The transmission frequency was chosen to be 22.125 GHz because at this frequency no power will reach the ground due to atmospheric absorption. The areas of the transmitter and rectenna were each assumed to be 1 km^2 and the transmitter and rectenna efficiencies are 30% and 50% respectively. Using these assumptions the LEO to GEO trip time for the MPD-COTV (including a 28.5° plane change) was calculated by integrating the equations of motion which included the dependence of the power transmission efficiency on the rectenna and transmitter separation distance. The results are presented in Fig. 4 where, for a payload of 10^6 kg and a transmitted power of 100 MW, the trip time is 105 days and the initial vehicle mass is 1.39×10^6 kg. Even with only this preliminary evaluation, this concept appears promising in terms of trip time and payload in addition to its elimination of the costly solar array and the need for subsequent annealing of the array after each trip. These calculations assumed 3 transmitters, but the concept is still feasible with only one transmitter, but the trip times will be longer. The single transmitter could be a SPS demonstration article that could be retrofitted with the high frequency transmitter.

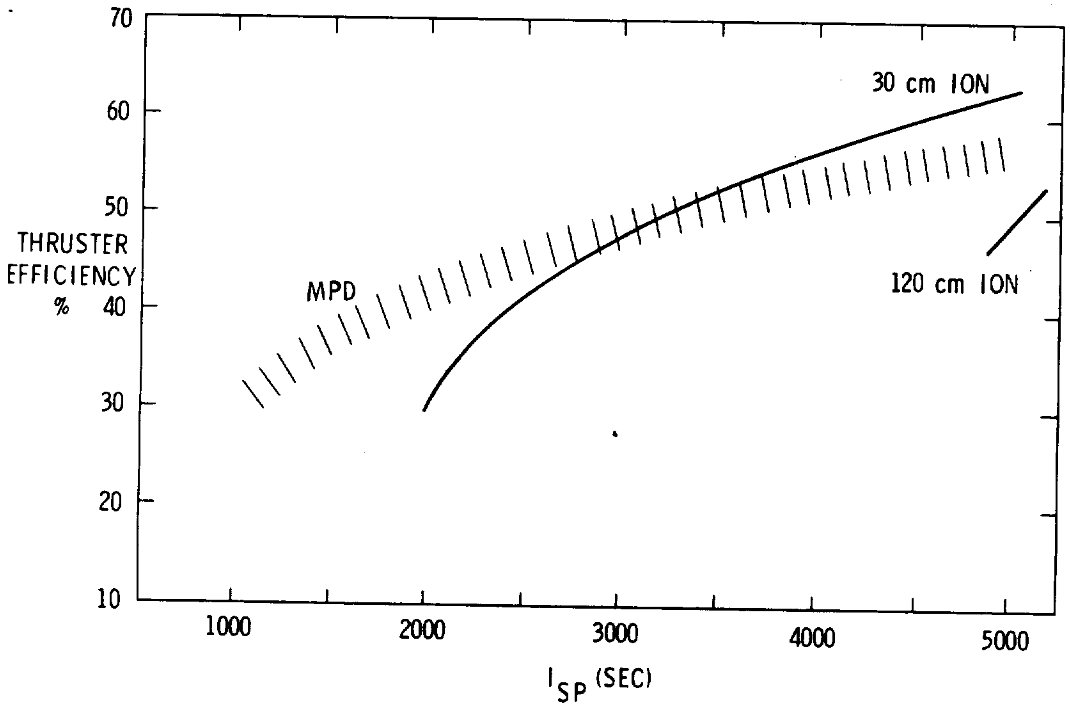

Fig. 1. Comparison of MPD and ion thruster efficiency with argon.

PAYLOAD - 2 x 10^6 KG

POWER - 150 MW

THRUSTER	SPECIFIC IMPULSE	EFFICIENCY	NUMBER OF THRUSTERS	TRIP TIME
120 CM ARGON ION (69 KW)	5000 SEC	51%	2000	205 DAYS
120 CM ARGON ION (150 KW)	8000 SEC	72%	920	213 DAYS
ARGON MPD (6 MW)	5000 SEC	57%	23	160 DAYS

Fig. 2. Solar array COTV mission performance with MPD and ion thrusters.

ASSUMPTIONS

- 1 KM^2 TRANSMITTER AND 1 KM^2 RECTENNA
- 50% EFFICIENT RECTENNA; 30% EFFICIENT TRANSMITTER
- TRANSMISSION FREQUENCY 22.125 GHz
- MPD-COTV RECEIVES POWER CONTINUOUSLY FROM ONLY ONE TRANSMITTER AT A TIME

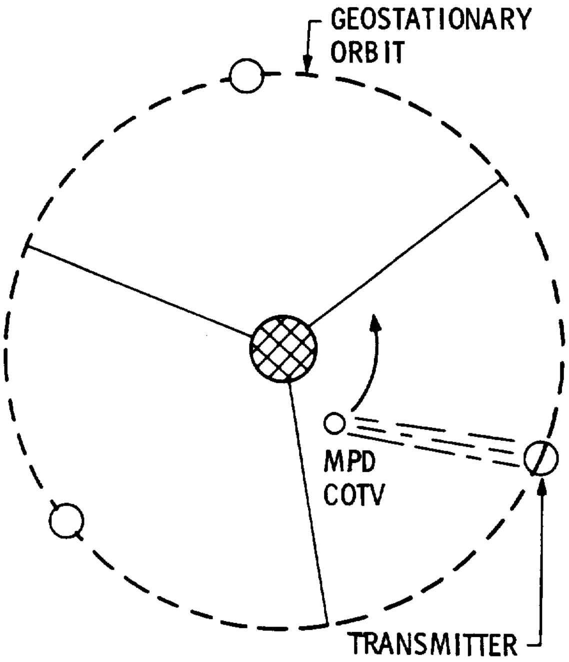

Fig. 3. Proposed microwave powered MPD-COTV concept.

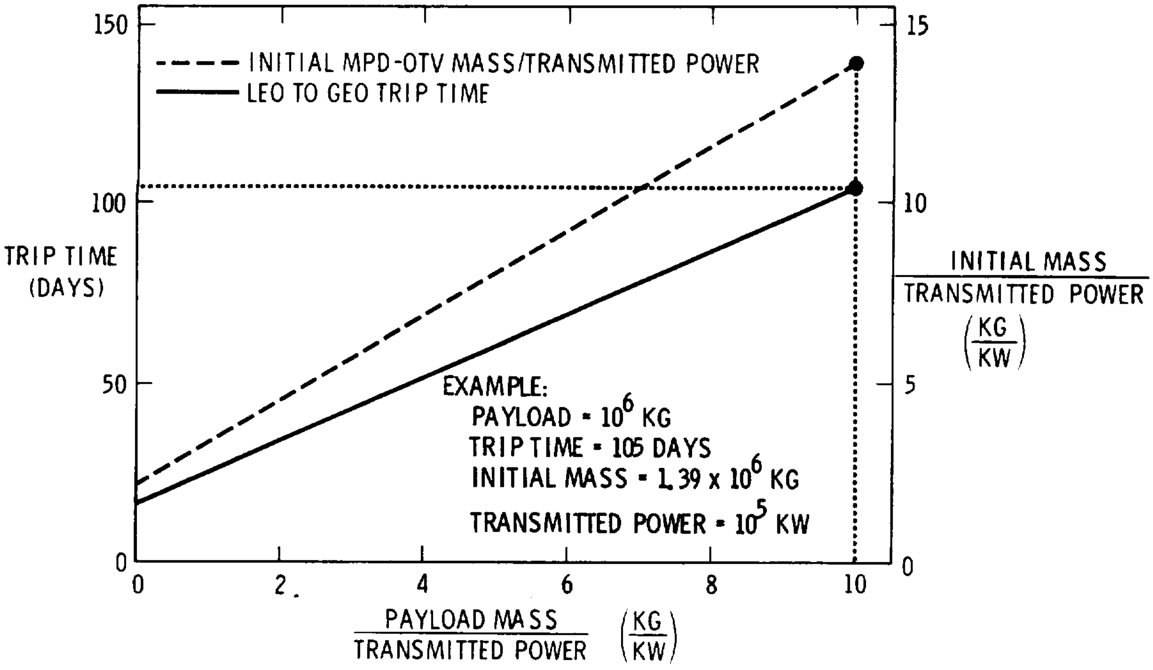

Fig. 4. Mission performance for microwave powered MPD-COTV.